Significance of High Soil Lead Concentrations for Childhood Lead Burdens

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The lead exposure of children and their mothers has been studied in two towns with mean soil lead contents of 900 and 400 ppm. No significant difference in blood or fecal lead contents was demonstrated between the two populations, but a small difference in hair lead content was shown. The blood lead content of children was greater than that of their mothers and was higher in the summer than in the spring samples. Children with pica for soil in the control area had increased lead content of blood and hair.

Preliminary data for children and mothers from villages with mean soil lead contents of 500 ppm and 10,000 ppm are reported which show significant differences in blood and hair lead content within the normal range. The data suggest that soil lead content of 10,000 ppm may result in increased absorption of lead in children, but to a degree which is unlikely to be of biological significance.

There has been increasing interest in the potential hazard to children resulting from the ingestion of soils or dusts containing concentrations of lead above normal, originating both from natural geological sources and from contamination resulting from industrial, mining, and smelting activity, as well as from lead additives in gasoline. The importance of this source of lead to childhood lead burdens is unknown, although at least one case of lead poisoning due to soil ingestion has previously been reported (*1*).

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A lead concentration of 15 ppm in soils is considered normal for virgin surface soils (*2*), but it can vary greatly, depending on the type of soil. Normal lead concentrations of less than 20 ppm have been reported in soils derived from sandstone, of 80 ppm in soils from quartz mica schist (*3*), and of 200 ppm in soils derived from black shale (*4*). Concentrations of several thousand ppm have been reported in city soils and dusts (*1,5,6*) which may, however, be "normal" for certain highly mineralized areas, such as that of the carboniferous limestone area of Derbyshire, which has been mined for lead and zinc since the Roman occupation of England.

Lead poisoning in cattle grazing in Derbyshire has been reported (*7*); this may have resulted from the ingestion of soil rather than high lead content pasture. Cattle have been shown to ingest large amounts of soil while grazing and may thus ingest up to ten times the amount of lead in the form of soil to that in herbage (*8*).

A regional geochemical survey of the area, undertaken by the group at Imperial College, revealed many stream sediments with lead concentrations exceeding 3000 ppm lead and surface soils near old mines and smelter sites containing up to 3% lead (*9*). On the basis of this survey, a study was undertaken in two towns differing in the lead content of their soil and located in a specific geochemically defined area in order to determine the significance that increased concentrations of lead in soil may have for local children. A similar study has recently been initiated in certain villages in the area which were found to have a mean soil lead content of approximately 10,000 ppm.

Sampling

Population samples in the two towns, Matlock and Buxton, were obtained through the local health authority and studied during April and May 1972. Children aged 2–3 years were chosen, since the prevalence of pica is high in this age group (*10*).

Interviews were conducted at a local clinic where the mother was questioned about the pica history of the child, where the child played, and whether the family grew or used locally grown produce. They were specifically asked if their child chewed or swallowed paint or soil, or mouthed soil-contaminated toys and fingers while at play.

Capillary blood samples were obtained from both mother and child in order to provide an index of short-term lead absorption. Dietary intake and intermediate exposure were estimated by a single fecal collection (*11*) and a sample of hair from the child, respectively (*12*). The same mothers and children were seen again during July and repeat samples obtained.

After visiting the individual homes, 30 children in Matlock and Buxton were found to have little or no soil in their gardens or to live in streets with higher than average traffic density for the area. Since these children did not normally come in contact with soil or might have had greater exposure to airborne lead than the majority of children in our study, they were excluded from further data analysis.

The lead content of the dust and rainfall and the suspended particulate matter in each town was monitored and soil samples taken from the home of each child. Six to ten subsamples, at a depth of 0–5 cm were combined to give surface soil samples from the front and back garden flower beds, the back garden lawn and, if present, the vegetable garden. A single sample was taken from the lawn at a depth of 30–45 cm. All samples were taken at least 2 m from the house.

In 1973 a similar study was initiated in neighboring lead-contaminated and control villages. Venous blood samples were taken from children aged 2–5 years and their mothers, as well as the hair and stool samples from the children. Samples of garden soil and house dust were obtained from each home.

Analysis

Capillary blood samples were analyzed by atomic absorption by using a Perkin-Elmer graphite furnace HGA-70, with a Model 305 spectrophotometer. Venous blood was analyzed by atomic absorption by use of a Delves cup procedure. At least three replicate analyses were performed on each sample.

The hair was washed with a nonionic detergent (Triton X-100) and the 2.5-cm segment adjacent to the scalp taken to indicate exposure over the previous two months (*13*). Stool samples were homogenized with distilled water and air samples collected on military filters (0.8 μm), equipment conforming to British Standard 1747 being used. The hair, feces, dustfall and air filters were wet-ashed with nitric and perchloric acids and analyzed by a semiautomated dithizone procedure.

Soil samples were oven-dried at 100°C, sieved to remove material greater than 2 mm, ground to less than 200 μm, and digested with nitric acid before analysis by flame atomic absorption spectroscopy.

Results

Soil lead data are summarized in Table 1. In addition to soils from the individual homes, data are presented on soils from grasslands in and around each town. The geometric mean is given, as the soil and biological data followed a lognormal distribution.

The values in the control town, Buxton, were greater than expected from the stream sediment survey, but there was at least a factor of two between the mean soil lead contents of the two towns. For each type of soil sample, the mean value in Matlock was significantly greater than the mean in Buxton (two tailed *t*-test, $P < 0.05$). The subsoil and topsoil lead concentrations of Matlock grassland sites were similar, indicating that the high soil lead concentrations in that area were probably due to mineralization.

The monthly dust and rainfall and the suspended particulate matter lead concentrations were found to be within the range for similar areas in England (*14*). For the year beginning June 1972, the mean lead concentration in suspended particulate matter was 0.61 $\mu g/m^3$ in Matlock (range 0.33–1.06) and 0.29 $\mu g/m^3$ in Buxton (range 0.12–0.47). Although there was a difference in concentration, the low values indicate that airborne lead was not contributing significantly to lead exposure in either of the two towns.

The blood lead data are summarized in Table 2. There was no significant difference in the mean blood lead concentrations of the children or mothers between the two towns, although the mean surface soil concentrations of 909 ppm in Matlock and 398 ppm in Buxton were significantly different ($P < 0.05$). Both children and mothers were found to have greater blood lead concentrations in the summer than the spring, and the children had higher blood lead concentrations than their mothers (paired *t*-tests, $P < 0.05$). This applied to children with or without current pica (Figs. 1 and 2).

In each town, comparisons were made between the children who had no current pica and those who had current pica for anything, and those who had current pica for soil (Table 3). In Matlock there was no significant difference in the mean blood or fecal

Table 1. Lead content of garden and grassland soils.

Type	Depth, cm	Town	Number of samples	Pb content, ppm		
				Mean	Geometric mean	Range
Front garden flower beds	0–5	Matlock	44	1263	925	164–7400
		Buxton	86	817	521	118–3300
Back garden flower beds	0–5	Matlock	36	1367	1028	305–5080
		Buxton	53	557	402	160–3300
Back garden lawn	0–5	Matlock	50	1121	784	230–8000
		Buxton	59	423	326	82–2640
Back garden lawn	30–45	Matlock	51	913	615	92–4400
		Buxton	68	295	217	46–1100
Vegetable garden	0–15	Matlock	8	980	770	270–1830
		Buxton	13	365	287	119–530
Grasslands	0–15	Matlock	5	1184	1139	660–1575
		Buxton	6	224	218	141–285
Grasslands	30–45	Matlock	5	1289	1130	555–2695
		Buxton	6	89	82	36–193

Table 2. Blood lead results.

	Children			Mothers		
		Pb, μg/100 ml blood			Pb, μg/100 ml blood	
	No.	Geom. mean	Range	No.	Geom. mean	Range
Matlock						
Spring	47	20.1	11–38	47	17.0	7–42
Summer	28	24.7	9–48	24	21.0	10–36
Buxton						
Spring	69	22.1	11–46	70	18.1	10–39
Summer	36	28.1	15–65	34	22.6	13–43

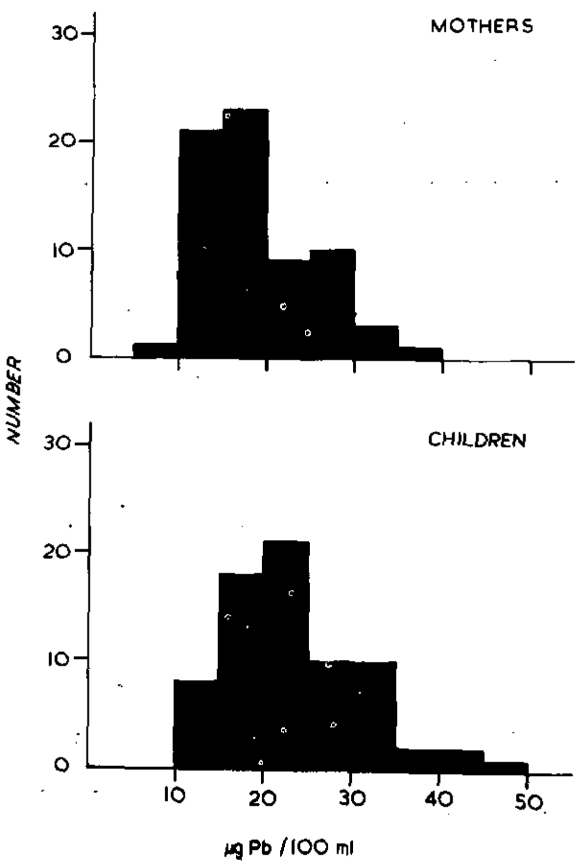

FIGURE 1. Blood lead concentrations of Buxton mothers and their children; spring 1972, $N = 68$.

lead values for these groups in either the spring or summer sampling. In Buxton, the only significant difference ($P < 0.05$) was found for the summer sample, where the children who have pica for soil had a greater mean blood lead concentration than the children who had no current pica.

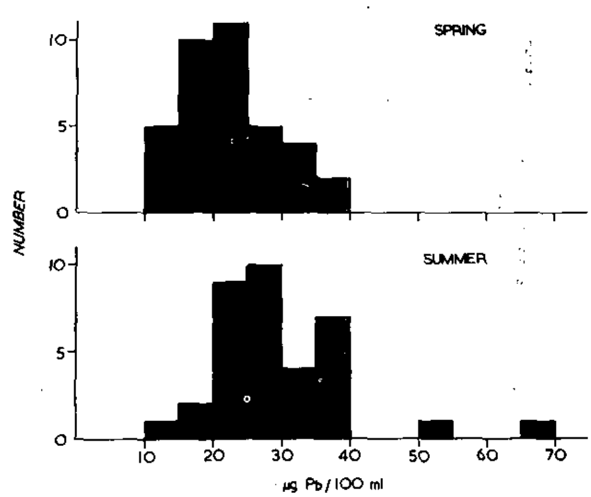

FIGURE 2. Blood lead concentrations of Buxton children; spring and summer 1972, $N = 35$.

Our definition of pica for soil included those children who habitually put fingers or toys in their mouths while playing in their gardens, as well as actually putting soil directly into their mouths, and included children who had pica for other substances in addition to soil. Of the 119 children in both towns, 51 conformed to our definition of pica for soil, but only 11 were definitely known by their mothers to have swallowed soil.

Although soil-eating children had a greater mean blood lead compared with those who had no current pica, the corresponding mothers also showed a similar difference (Table 4), suggesting that the increased blood lead was due to factors other than soil. This finding illustrates the value of also

Table 3. Blood and fecal results.

	April			July			
	Blood lead, $\mu g/100$ ml		Feces, μg/sample	Blood lead, $\mu g/100$ ml		Feces, μg/sample	Surface soil, $\mu g/g$ dry soil
	Child	Mother		Child	Mother		
Matlock							
All	20.1 (47)[a]	17.0 (47)	67.8 (47)	24.7 (28)	21.0 (24)	65.8 (27)	909 (47)
No or past pica	19.0 (19)	17.0 (19)	75.6 (19)	24.2 (13)	22.9 (11)	73.1 (12)	904 (19)
Present pica	20.9 (28)	16.9 (28)	63.0 (28)	25.2 (15)	19.5 (13)	60.4 (15)	912 (28)
Present pica for soil	20.4 (14)	15.3 (14)	64.0 (14)	25.2 (8)	18.4 (7)	54.0 (8)	709 (14)
Buxton							
All	22.1 (69)	18.1 (70)	69.4 (68)	28.1 (36)	22.6 (34)	67.8 (39)	398 (72)
No or past pica	21.5 (15)	16.8 (15)	60.2 (15)	22.5 (7)[b,c]	19.9 (7)	56.6 (7)	380 (15)
Present pica	22.2 (54)	18.5 (55)	72.3 (53)	29.8 (29)[c]	23.4 (27)	70.5 (32)	403 (57)
Present pica for soil	22.6 (37)	18.9 (37)	81.0 (36)	31.5 (16)[b]	22.4 (14)	78.0 (19)	406 (38)

[a] Number of samples.
[b] Significantly different, $P<0.05$.
[c] Significantly different, $P<0.1$.

Table 4. Blood and concentrations of children who eat soil and children with no present pica.

	Children			Mother		
		Pb, $\mu g/100$ ml			Pb, $\mu g/100$ ml	
	No.	Geometric mean	Range	No.	Geometric mean	Range
Buxton						
No pica	15	21.5[a]	11–32	15	16.8[c]	10–39
Soil eaters	7	27.3[a]	13–36	6	21.4[c]	11–29
Matlock						
No pica	19	19.0[b]	15–38	19	17.0	11–30
Soil eaters	4	28.2[b]	15–38	4	21.4	16–28

[a,b] Significantly different, $P<0.1$.
[c] Significantly different. $P<0.005$.

sampling the mother as a further indication of the environment of the child.

The hair lead results provided no conclusive evidence of an effect of soil lead on childhood lead exposure (Table 5). While in Buxton the children with pica for soil had a statistically greater mean hair lead concentration than those without a current pica history, the values are low and within the normal range. The children in Buxton with current pica for anything also had a greater mean hair lead concentration but no comparable difference was demonstrated in Matlock, the town with the greater soil lead content.

The individual results were related to the soil lead values found at each child's home by product-moment correlations of the raw and log-transformed data, as well as the nonparametric Kendal rank correlation. No statistically significant correlations between the blood, fecal, or hair lead values and the soil lead levels in the immediate environment of the child were found by these methods.

Further studies are currently being conducted in two groups of villages near Matlock and Buxton, where the mean soil lead concentrations are approximately 10,000 ppm and 500 ppm. The homes with the higher lead soil concentrations are in villages near extensive old mine workings and some are, in fact, built on old waste material.

The blood and hair analyses have been completed, and the preliminary data are given (Table 6 and Fig. 3 and 4). The children were divided into the high and low soil lead areas on the basis of soil samples taken prior to the survey, and any final interpretation must await the analysis of the soils from the individual homes.

The range of the values found were 13–45 μg/100 ml for the children's blood, 9–44 μg/100 ml for the mothers' blood, and 2–62 μg/g for the hair samples. All children and mothers living in the high soil lead area had greater mean blood and hair levels than those living in the low soil lead area, as well as those children with no current pica history. Although these differences are significant at the 95% confidence level, it should be noted that all the observed values were within the accepted normal range.

Comparison of the data for children with present pica for soil and those with no current pica showed that only the hair results in the high soil lead area were significantly different. The 16 children with pica for soil had a mean hair lead concentration of 21 ppm compared with a mean of 11 ppm for

Table 5. Lead in hair.

	Pb. μg/g hair			
	Spring		Summer	
	Geometric mean	Range	Geometric mean	Range
Matlock				
All	6.7 (47)[a]	3.1–21.2	8.1 (33)	2.3–45.7
No or past pica	5.7 (19)	3.1–17.2	8.3 (15)	2.3–45.7
Present pica	7.7 (28)	4.0–21.2	8.1 (18)	2.5–38.7
Present pica for soil	6.5 (14)	4.0–15.8	6.8 (9)	2.5–38.7
Buxton				
All	5.0 (71)[a]	0.8–36.0	7.4 (40)	2.1–47.5
No or past pica	3.6 (15)[b,c]	0.8– 6.9	4.4 (8)[d,e]	2.1–11.3
Present pica	5.5 (56)[b]	2.7–36.0	8.0 (32)[d]	2.1–47.5
Present pica for soil	5.7 (38)[c]	2.9–36.0	8.2 (19)[e]	3.7–47.5

[a,b,c,d,e] Pairs significantly different, P<0.05.

Table 6. 1973 Derbyshire survey: preliminary blood and hair results.

	Geometric means[a]		
	Blood, μg Pb/100 ml		Hair, μg Pb/g.
	Child	Mother	
High soil lead area			
All	25.0 (48)[b]	18.0 (44)[c]	12.8 (48)[d]
No current pica	23.6 (27)[e]	18.1 (26)	10.8 (27)[f,g]
Present pica	26.8 (21)	17.6 (20)	15.8 (21)
Present pica for soil	26.4 (16)	17.5 (16)	21.1 (16)[g]
Low soil lead area			
All	20.9 (34)[b]	14.7 (30)[c]	7.5 (34)[d]
No current pica	19.9 (17)[e]	14.6 (16)	5.7 (17)[f]
Present pica	21.9 (17)	14.6 (15)	9.8 (17)
Present pica for soil	22.1 (16)	14.5 (14)	9.0 (16)

[a] Numbers of individuals in parentheses.
[b,c,d,e,f,g] Pairs significantly different, $P<0.05$.

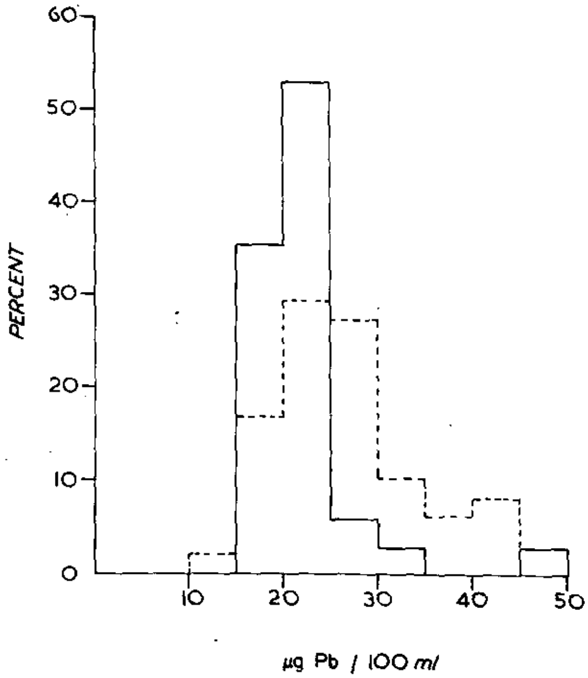

FIGURE 3. Children's blood lead concentrations, 1973 preliminary results: (- -) high soil lead area, $N = 48$; (——) low soil lead area, $N = 34$.

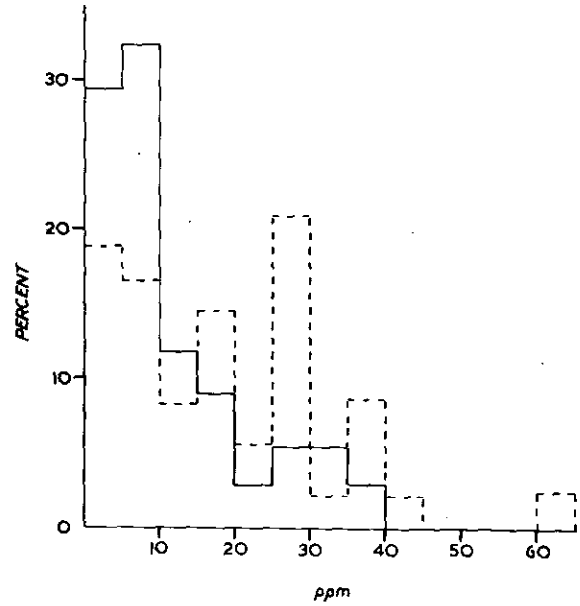

FIGURE 4. Children's hair lead concentrations, 1973 preliminary results: (- -) high soil lead area, $N = 48$; (——) low soil lead area, $N = 34$.

the 27 children without current pica ($P < 0.05$). There was no statistically significant difference in the mean blood lead concentrations. Further data analysis will take into account any age differences and the results of the analysis of the garden soils and house dusts from the individual homes.

Discussion

While the data suggest that there is increased lead exposure for children living in high soil lead areas, there is no evidence that this is sufficient to be of biological significance. Pica for soil, although prevalent to an unexpected degree, appears to be a relatively unimportant source of lead for children. This could be due either to the small amounts of soil being ingested or the relatively poor bioavailability of lead in the ingested material, similar to the poor uptake of lead by plants (*15*).

Since soil type may greatly influence the bioavailability of lead in ingested soil, the control villages for the study in progress were carefully selected to represent similar soil parent material with a relatively low lead content.

Further studies on the significance of lead in soil and dusts for childhood lead burdens are in progress. The amounts of soil ingested by children and the factors which may influence the availability of lead from various types of soil and city dust are being investigated by tracer, leaching and animal feeding studies.

The results of our studies to date suggest that local soil lead levels of the order of 10,000 ppm are without major significance and that on present evidence the recent concern with regard to contaminated soils in cities is not well founded.

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